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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

In re PATENT APPLICATION of	Confirmation No.: 6577
MOKVELD et al	Group Art Unit: 1771
Appln. No.: 09/842,373	Examiner: L. Salvatore
Filed: April 26, 2001	Attorney Docket: 121640-40280261

Title: PROCESS FOR THE PRODUCTION OF A SHAPED ARTICLE

* * * * * * * * *

March 1, 2005

APPELLANTS' BRIEF UNDER 37 C.F.R. § 41.37

Mail Stop POBA
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22131-1450

Sir:

Further to the Notice of Appeal under 37 C.F.R. 43.31 filed December 3, 2004, Mokveld et al, Appellants herein, appeal from the decision of the Primary Examiner, dated June 3, 2004, finally rejecting claims 11-14, and 16-24, all of the claims pending in this application. This appeal is taken with respect to all of the finally rejected claims.

The $500.00 fee required by 37 C.F.R. 41.20(b)(2) is authorized to be charged to Deposit Account 503-121; please reference Attorney Docket: 121640-40265189. Please charge any additional fees associated with the submission of this paper to Deposit Account Number 503-121. The Commissioner for Patents is also authorized to credit any over payments to the above-referenced Deposit Account.

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(i) ***Real party in interest.***

The assignee of the subject application and the real party in interest is DSM IP Assets, B.V., Heerlen, The Netherlands.

(ii) ***Related appeals and interferences.***

There are no related appeals or interferences.

(iii) ***Status of claims.***

Claims 11-14 and 16-24 are pending and are finally rejected. Claims 11 and 14 are the only independent claims.

Claims 1-10 and 15 are cancelled.

This appeal is taken with respect to all of the finally rejected claims 11-14 and 16-24.

(iv) ***Status of amendments.***

No amendments were filed subsequent to the date of the Final Rejection.

(v) ***Summary of claimed subject matter.***

The claimed subject matter, as set forth in independent claim 11, relates to a shaped article obtained by compression of one or more fiber layers containing polyolefin fibers. In particular, the fiber layers contain from 0.05 to 5 wt% of a solvent for the polyolefin, relative to the weight of the polyolefin fibers and the solvent in the fiber layers.

Thus, as set forth in independent claim 11 (with sub-paragraphing added) the shaped articles (page 3, lines 6-10) are

i) obtained by compression (page 13, line 1 to page 14, line 2)

ii) of one or more (page 3, lines 2-6)

iii) fiber layers (page 3, lines 23-27; lines 27-30; page 3, lines 1-10)

iv) containing polyolefin fibers (page 4, lines 11-24)

v) wherein the fiber layers contain 0.05 to 5 wt.% (page 7, lines 15-17)

vi) of a solvent for the polyolefin (page 8, lines 12-30)

vii) relative to the weight of the polyolefin fibers and solvent in the fiber layer (page 2, lines 14-20).

As noted in connection with embodiments of the invention, such as, for example, specifically set forth in claims 21-24, which depend, directly or indirectly from claim 11, the shaped articles may be particularly advantageous in connection with anti-ballistic applications. That this was found to be true, notwithstanding the content of solvent in the shaped article (see, e.g., page 2, lines 21-30 and page 3, lines 1-3), was not expected based on the current knowledge in the art. In this regard, the quality of antiballistic articles is generally described in terms of its Specific Energy Absorption (SEA) (page 1, lines 17-29). As described on page 2, lines 21-30 and page 3, lines 1-3, the high SEA values of the antiballistic shaped articles according to the invention is surprising since the solvent has no antiballistic effect, *per se*, but does contribute to increasing the areal density which would have been expected to lower SEA values. In accordance with a particular embodiment of the invention, the shaped article has an SEA (on impact of an AK47 MSC point) of at least 115 J/kg/m^2 (page 15, lines 1-3; claim 13).

Independent claim 14 provides additional details of the shaped article and is generally described at, for example, page 14, lines 20-30 and page 15, lines 1-3. According to claim 14, the shaped article contains two or more fiber layers compressed on top of one another (page 4, lines 1-6). The fiber layers contain highly oriented (page 4, line 29 to page 5, line 1) polyethylene fibers (page 4, line 18) having a modulus of tension of at least 800 g/den (page 5, line 3) and a tensile strength of at least 30 g/den (page 5, lines 4-5). At most, 30% by weight (based on the total weight of fiber layer) of a matrix material is present in the fiber layers (page 14, lines 20-24). The fibers in each layer are unidirectionally oriented (page 10, lines 3-25) and are at an angle relative to the fibers in neighboring layers (page 3, lines 9-13; page 14, lines 24-27). Furthermore, the fibers have an intrinsic viscosity of at least 5 dl/g (page 5, lines 18-20), and a fineness of less than 5 denier per filament (page 6, lines 5-9). An amount of non-volatile solvent (page 11, lines 27-30) in the range from 0.05 to 5 wt% (page 10, lines 17-20) is present in the fiber layers. The shaped article has a specific energy absorption (SEA) on impact of an AK47 MSC point of at least 115 $J/kg/m^2$ (page 15, lines 1-3).

The solvent may be added to the fibers by contacting the fibers with the solvent or solvent mixture. Alternatively, the solvent may be introduced during fiber formation, such as by spinning a polyolefin fiber solution and not entirely removing the solvent (see, e.g., page 7, lines 18-30 and page 8, lines 1-11).

The effect of including small amounts of solvent in the fiber layers of the shaped articles prior to compression may be appreciated from the examples in the specification. For instance, as shown in Examples 3-7, page 18, the addition of 0.4 to 1.2 wt% solvent (e.g., paraffin) resulted in an increase in the V50 (m/s) (where $SEA = 0.5 \times m \times V50^2/AD$, where V50 = velocity of projectiles fired at the shaped article at which 50% of the projectiles - here, AK47 MSC rounds - pass right through the shaped article and AD = areal density – see page 1, lines 22-26) for two different types of fibers (e.g., polyethylene).

(vi) ***Ground of rejection to be reviewed on appeal***

The ground of rejection to be reviewed is:

Whether the Examiner has erred in rejecting claims 11-14 and 16-24, under 35 U.S.C. § 103(a), as being unpatentable over Van der Loo (WO 97/00755) (van der Loo) in view of Nanri et al, JP 360151311A (Nanri).

(vii) ***Arguments***

The present invention, as defined by the claims presented on appeal, is concerned with shaped articles obtained by compression of one or more, preferably two or more, fiber layers containing polyolefin fibers. The fiber layers contain from 0.05 to 5 wt% of a solvent for the polyolefin. These shaped articles are especially useful as anti-ballistic molded articles and, in this capacity, may be characterized, in specific embodiments, by a Specific Energy Absorption (SEA), on impact of an AK47 MSC point, of at least 115 J/kg/cm^2.

The prior art does not disclose such solvent containing molded shaped articles and does not disclose achieving such high SEA values.

Therefore, the Honorable Board of Patent Appeals and Interferences should not sustain the final rejection in this case for the above and the following more detailed reasons:

(1) *van der Loo discloses anti-ballistic shaped articles from compressed layers of polyolefin fibers but explicitly avoids solvent in these shaped articles.*

Van der Loo is concerned with improving the Specific Energy Absorption (SEA) levels of ballistic-resistant molded articles. This objective is achieved by increasing the density ρ_f of the compressed stack in the ballistic-resistant molded article to at least 98.8% of the theoretical maximum density (page 2, lines 6-10). To achieve the high densities it is disclosed that, for example, the manufacture should proceed with as few low-density components as possible remaining in the molded article (page 8, lines 1-4). The patentees disclose compressing a stack of

monolayers of polyolefin fibers at a pressure of at least 5 MPa in order to approach more closely the theoretical maximum density and to achieve higher SEA values (*see, e.g.*, page 8, lines 19 *et seq.*) The highest SEA value reported by van der Loo is 114 $J/kg/m^2$ (*see* Table 4, page 17).

At the same time, the patentees explicitly avoid solvents in the molded articles. For instance, reference is made to the following disclosures:

- Page 4, lines 14-15: "Preferably, <u>uncoated</u> fibers are used."
- Page 4, lines 28-30: "If a solution or a dispersion of the plastic is used in the manufacture of the monolayer, the process also comprises <u>evaporating the solvent or dispersant</u>."
- Page 6, lines 2-12: "Preferably, use is made of polyethylene fibres consisting of polyethylene filaments prepared by a gel-spinning process .... This process essentially comprises the preparation of a solution of a polyolefin of high intrinsic viscosity, ... and drawing the filaments <u>before, during or after removal of the solvent</u>."

(All emphases added.)

In addition, however, the practitioner, being aware of the general incompressibility of liquids, would further be disinclined from including a fiber having a liquid coating, such as liquid paraffin, in the monolayers of fibers to be compressed.

Accordingly, the practitioner would understand that the fibers and fiber layers used to manufacture the ballistic-resistant molded articles described by van der Loo should not contain a solvent for the polyethylene fibers, such as liquid paraffin.

(2) *The prior art, as a whole, at the time the present invention was made, explicitly teaches to avoid using solvent or lubrication or low-friction fibers in the preparation of anti-ballistic shaped articles.*

The prior art, as a whole, at the time the invention was made, teaches that fibers with low coefficient of friction would <u>not</u> be suitable for a ballistic resistant molded article. The low coefficient of friction would have been expected to facilitate an impacting object to move

filaments apart and, certainly, this would be very undesirable in a ballistic resistant article. Such common knowledge is evidenced, for example, in the following prior art of record.

For example, the review book, "Ballistic materials and penetration mechanics" by Roy C. Laible (Ed.), Elsevier Science Publishers, on pages 75, 81 and 88 (1980) is especially relevant. On page 75, first full paragraph, it is explained that nylon fibers occasionally "fell below its projected performance of a ballistic limit ..." and that one reason "for this failure was considered to be the slipperiness of the fabric due to residual spinning oils which in turn caused yarn-to-yarn slippage."

On page 81, it is reported that the ballistic resistance of polypropylene is always lower than that of nylon despite its higher strength. It is explained that "one possible reason for the relatively low ballistic resistance of polypropylene is the low yarn-to-yarn friction exhibited by polyolefin base fibers." In fact, it is reported that attempts to increase the yarn-to-yarn friction or to decrease the friction with a lubricant "were unsuccessful as judged by little change in ballistic limit values."

The adverse effects of low friction is further discussed on page 88. Here, it is explained that losses in the ballistic protectivity of Kevlar fabric against 0.22 caliber projectiles results from exposure to moisture which "can lubricate the yarns enough to aid the passage of the missile without breaking yarns and absorbing energy."

Therefore, from this level of skill in the art, the practitioner would have recognized the general principal that any alleged advantages of the polyethylene fibers of Nanri for Nanri's objectives of improving clothing and ropes, would be converted to profound disadvantages in anti-ballistic applications, such as the ballistic-resistant molded articles of van der Loo.

From U.S. 5,035,111 and U.S. 5,225,241, it is again evident that prior art attempts to improve the anti-ballistic performance of fibers with low friction have not been successful.

For instance, in U.S. 5,035,111, it is explained that filaments having high tensile strength and a high modulus tend to have a high molecular weight and be highly drawn yet, because the surface of such filament is, in general, very smooth, the coefficients of friction are very low.

> "Such filaments, or rather yarns, wovens, knits or nonwovens produced therefrom, are used for many purposes where the high tensile strength and the high modulus ... are useful. *** However, wovens or nonwovens produced from such filaments have the disadvantage that the smooth surface, and hence the low coefficient of friction, of the filaments ... and the good gliding action make it relatively easy for an impacting bullet to move these filaments apart, so that despite the high tensile strengths and moduli of such plastic filaments, the bulletproof wovens and non-wovens produced therefrom are still not totally satisfactory." (column 1, lines 12-31).

Similarly, U.S. 5,225,241 at column 1, lines 14-20 reveals that such fibers having a low coefficient of friction,

> "when used in the construction of ballistic fabrics, exhibit poor energy transfer to neighboring fibers during ballistic impact, resulting in loss of stopping efficiency."

It is respectfully submitted that these consistent and negative disclosure of the effects of low coefficient of friction in the prior art, and which are totally consistent with the exclusion of solvents in the antiballistic articles of van der Loo, would have been understood by the practitioner as applying generally to polyolefin fibers in all types of constructions and not only to woven or nonwoven polyolefin layers which have not been subjected to compression.

(3) *Nanri discloses striated polyethylene fibers for use in clothing and ropes, wherein solvent is included for decreasing fiber-to-fiber friction,* i.e., *increasing slipperiness.*

According to the disclosure of Nanri, polyethylene yarns having improved processing properties, frictional resistance, and wear resistance for use in clothing, ropes and fish netting, are achieved by providing such yarns with a certain flatness ratio and a great number of channels (striations) arranged in the fiber axis direction and by containing from 0.05 to 1.0 wt% of liquid paraffin (*see, e.g.,* claims 1 and 2; page 4, third full paragraph).

Nanri explains that the polyethylene fibers have excellent resistance against friction (*e.g.*, "particularly excellent resistance against abrasion" English translation, page 3, lines 3-4 from bottom). At least in part, this improvement of resistance against friction abrasion results from the multi-striate grooves in the flat fibers (*see, e.g.*, page 5, lines 18-21 "when multi-striate grooves are given to the polyethylene fiber, the friction coefficient of the fiber surface declines") and from the liquid paraffin content of the polyethylene filaments (*see, e.g.*, page 6, lines 1-15).

It is respectfully urged that, in view of the low coefficient of friction of the polyethylene filaments disclosed by Nanri, the practitioner would not have been motivated to use such polyethylene filaments as the polyethylene filaments of van der Loo and, in fact, would be dissuaded from using these filaments in the environment of van der Loo.

(4) *One of ordinary skill in the art at the time the present invention was made would not have been motivated to utilize Nanri's low-friction polyethylene fibers in the anti-ballistic compressed molded articles of van der Loo*

It has been suggested that the low friction property of the fibers of Nanri "would not negatively effect the impact resistance properties of a moulded ballistic article comprising a *compressed* stack of single layers." This was explained further by the assumption that "since the ballistic article in question comprises a moulded *compressed* stack of layers, any frictional properties would inherently be lost upon compression. Thus, having low or high frictional polyethylene fibers would not materially affect the final product structure since all layers are *compressed* to form a moulded article. The burden is shifted to Applicant to evidence otherwise." (All emphases in original.)

Appellants respectfully disagree with these assumptions and submit that there is no basis for the assumption that the practitioner of ordinary skill in the art would have disregarded the explicit disclosures in the prior art of the drawbacks of solvent or low coefficient of friction for anti-ballistic properties, as being applicable to the compressed fiber layers of van der Loo.

This is evident from the clear and unambiguous instructions by van der Loo to remove any solvent from the fibers prior to subjecting the fiber layers to compression.

While it is stated that the burden to prove otherwise is shifted to Appellant, it is respectfully submitted that no objective evidence has been set forth which supports the assertions set forth in the rejection. It is not satisfactorily explained why *compression* would inherently result in loss of any frictional properties. This is true notwithstanding the assertion that,

> "compression would hold the fibers in place such that there is no movement between the fibers and fiber layers. Thus, the frictional properties are not considered relevant since the fibers are tightly compacted during the formation of the molded shaped article."

This assertion does not, for example, take into consideration that even for tightly compacted fibers the impact of a projectile, such as a bullet, would be expected to penetrate further through the molded article when the friction between the fibers is reduced. Thus, as explained in U.S. 5,225,241, fibers having a low coefficient of friction, "when used in the construction of ballistic fabrics, exhibit poor energy transfer to neighboring fibers during ballistic impact, resulting in loss of stopping efficiency." This statement of the knowledge of the skilled practitioner is not dependent on whether or not the fibers are compressed and is directly opposed to the position taken by the Primary Examiner in the Final Rejection of the appealed claims.

Moreover, the assumption of the Primary Examiner overlooks the additional facts, as already explained in the specification of this application, that inclusion of a solvent in an antiballistic fabric article would not be considered of any benefit to the practitioner at least for the reasons that (1) solvents do not contribute to the antiballistic properties, e.g., tensile strength and modulus; and (2) solvent would increase the areal density of the antiballistic fabric thus be expected to reduce the SEA of the fabric.

With regard to factor (1), according to van der Loo, for fibers to be "ballistically effective" they should have a high tensile strength of, preferably, at least 1.2 GPa (>14 g/d), a high tensile modulus, preferably at least 40 GPa (>467 g/d) and/or a high energy absorption. It is indicated

that preferred polyethylene fibers have a tensile strength of at least 35 cN/dtex (>40 g/d), a tensile modulus of at least 1000 cN/dtex (>1133 g/d). Therefore, the practitioner of ordinary skill in the art would appreciate that the high molecular weight polyethylene fibers available for use in the ballistic-resistant molded articles, such as described on pages 5 and 6 of van der Loo, already possess the tensile strength and tensile modulus values, required for anti-ballistic molded articles. Accordingly, since the tensile strength and tensile modulus values suggested by Nanri (tensile strength 30 g/d or more, page 6, fifth paragraph) are not any higher than already commercially available, without the flattened cross-section and without the presence of liquid paraffin solvent as required by Nanri, the practitioner would not have been motivated to turn to Nanri's lubricated polyethylene filaments as relevant to the anti-ballistic molded articles of van der Loo.

With regard to the second factor, according to Nanri, the purpose of the liquid paraffin solvent is merely to increase the resistance against friction abrasion, namely, to reduce the coefficient of friction.

Therefore, even if there was a basis for limiting to only non-compressed fabrics the knowledge in the art relating to the effect of solvents on increasing lubricity and decreasing antiballistic performance, there is still no evidence to explain why the practitioner would have been motivated to incorporate into a ballistic resistant molded article a substance, such as solvent, which does not contribute to antiballistic performance but which would be expected to decrease the SEA of the article.

As noted above, there is no evidence that liquid paraffin or any other solvent contributes to the tensile strength or modulus of elasticity, which are principal parameters for ballistic resistant fibers. Therefore, given the uncontested evidence that a low coefficient of friction is detrimental to ballistic properties, the practitioner would not have, under any circumstances, been motivated to incorporate the liquid paraffin laden fibers of Nanri in fabricating a ballistic resistance shaped article as contemplated by van der Loo. The practitioner simply would not have expected the liquid paraffin-containing fibers of Nanri to contribute to additional benefits in tensile strength and modulus of elasticity or, to improvement in the SEA value. Therefore, in view of the known

detrimental affects of low coefficient of friction, the practitioner would not have even bothered to try to determine the effect of compression on the coefficient of friction.

Furthermore, there is no basis for the conclusion that the compression of a stack of fiber layers in the shaped articles of van der Loo, would have, if applied to the fibers of Nanri, overcome the difficulty of a low coefficient of friction with regard to the effect on ballistic properties. In this regard, as clearly described by Nanri, the multi-striate grooved construction is itself considered to contribute to the low coefficient of friction (see, *e.g.*, page 5, second full paragraph, of the English translation of Nanri).

Accordingly, whether for single layers or compressed stacks of multiple layers, the practitioner of ordinary skill in the art would not have been motivated by the disclosure of Nanri to modify the shaped articles of van der Loo by using Nanri's liquid paraffin-containing polyethylene fibers. Rather, the practitioner skilled in the art relating to ballistic-resistant molded or shaped articles as disclosed by van der Loo and informed of the negative impact of low coefficient of friction on ballistic properties, would not have had a reasonable expectation of success in using paraffin-containing polyethylene fibers, including those disclosed by Nanri, as an alternative to the polyethylene fibers used by van der Loo.

Accordingly, it is respectfully submitted that the Patent and Trademark Office has not presented evidence which would create a *prima facie* case of obviousness of the embodiments of Appellants' invention as defined by claims 11-14 and 16-24. Rather, the evidence regarding the negative impact of low coefficient of friction on ballistic resistant shaped articles coupled with the disclosure of the low coefficient of friction of the Nanri polyethylene fibers and the absence of evidence to support an assertion that the low coefficient of friction, or at least its impact on ballistic properties, is inherently lost upon compression of a stack of layers, all lead to a conclusion that Appellants are entitled to obtain a patent for the subject matter being claimed.

Reversal of the rejection of claims 11-14 and 16-24, as unpatentably obvious, within the meaning of 35 U.S.C. §103(a) is, therefore, respectfully requested.

Evidence of unexpected results as indicia of non-obviousness.

While it is submitted for the reasons set forth above, that the subject matters of claims 11-14 and 16-24, would not have been *prima facie* obvious over van der Loo and Nanri, it is further submitted that the evidence of record, by way of the examples in the specification of the subject application, demonstrate unobvious and unexpected results.

Specifically, although there is no evidence or reason why the practitioner would have expected inclusion of liquid paraffin in an anti-ballistic molded article to have improved ballistic performance, this is precisely what is demonstrated in the Examples and comparative examples in the application.

Thus, looking at the results for Comparative Example C (no solvent) in comparison to the results for Examples 3-7 (from 0.4 to 1.2% paraffin oil), the value of V50 (m/s) increases from a value below 710 to values ranging from 730 to 820. Since the value of SEA is proportional to the square of V50 (SEA = 0.5 x m x $V50^2$/AD; where m is the mass of the projectile and AD is the areal density), the increase in the SEA values will be even greater.

Since there is no evidence to suggest such an effect by including liquid paraffin in an anti-ballistic molded shaped article, the results achieved by the present invention would not have been expected by the person of ordinary skill in the art. This is believed to be strong evidence that the subject matter as a whole would not have been obvious at the time the invention was made.

Therefore, for any and all of the reasons set forth herein, the rejection of claims 1-14 and 16-24 under 35 U.S.C. § 103(a) as being unpatentable over Van der Loo taken with Nanri, should not be sustained, and should be reversed by the Honorable Board of Patent Appeals and Interferences.

Respectfully submitted,
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(viii) CLAIMS APPENDIX

1-10 and 15. Cancelled.

11. Shaped article obtained by compression of one or more fiber layers containing polyolefin fibers, wherein the fiber layers contain 0.05 to 5 wt.% of a solvent for the polyolefin, relative to the total weight of the polyolefin fibers and solvent in the fiber layer.

12. Shaped article containing two or more fiber layers compressed on top of one another, said fiber layers containing polyolefin fibers and 0.05 to 5 wt.% of a solvent for the polyolefin on and/or in the fibers.

13. Shaped article according to Claim 11, wherein the SEA on impact of an AK47 MSC point is at least 115 $J/kg/m^2$.

14. Shaped article containing two or more fiber layers compressed on top of one another, containing highly oriented polyethylene fibers having a modulus of tension of at least 800 g/den and a tensile strength of at least 30 g/den, and at most 30 wt.% of a matrix material, relative to the total weight of the fiber layer, the fibers in the fiber layers being unidirectionally oriented and at an angle relative to the fibers in neighbouring fiber layers, said fibers having an intrinsic viscosity of at least 5 dl/g, and a fineness of less than 5 denier per filament and 0.05 to 5 wt.% of a non-volatile solvent, said shaped article having a specific energy absorption on impact of an AK47 MSC point of at least 115 $J/kg/ m^2$.

16. A shaped article according to Claim 12, wherein the polyolefin fibers are highly oriented polyethylene fibers having an intrinsic viscosity of at least 5 dl/g, a tensile strength of at least 30 g/den, and a modulus of tension of at least 800 g/den.

17. A shaped article according to Claim 12, wherein the solvent has been applied by distributing the solvent on one or more of the fiber layers before compression.

18. A shaped article according to Claim 12, wherein the fiber layers before compression contain solvent-containing polyolefin fibers with a solvent content of 0.05 to 5 wt.%.

19. A shaped article according to Claim 12, wherein the polyolefin fibers comprise polyethylene fibers having a fineness of less than 5 denier per filament.

20. A shaped article according to Claim 12, wherein the fiber layers comprise unidirectionally oriented fibers, the direction of the fibers in the fiber layers being at an angle relative to that of the neighboring fiber layers.

21. An anti-ballistic shaped article comprising the shaped article according to Claim 12, wherein the solvent content is 0.1 to 2 wt%.

22. An anti-ballistic shaped article comprising the shaped article according to Claim 12, wherein the polyolefin fibers comprise polyethylene and wherein the chi-parameter of the solvent relative to polyethylene, at 289 °K, is less than 0.5.

23. An anti-ballistic shaped article comprising the shaped article according to Claim 12, wherein the solvent is a non-volatile paraffin.

24. An anti-ballistic shaped article comprising the shaped article according to Claim 11, which has been compressed at a pressure which is higher than 165 bar, at a compression temperature which is higher than 125°C and with a solvent content from 0.1 to 2 wt %.

(x) RELATED PROCEEDINGS APPENDIX

None.

(ix) EVIDENCE APPENDIX

Affidavits/Declarations

None

Other Evidence/Literature

"Ballistic Materials and Penetration Mechanics" Roy C. Laible (Ed.), Elsevier Publishers, 1980, pp. 75, 81, 88

U.S. 5,035,111 to Hogenboom et al, issued July 30, 1991

U.S. 5,225,241 to Dischler, issued July 6, 1993

BALLISTIC MATERIALS AND PENETRATION MECHANICS

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arms missiles were defeated. In addition to actual defeat of the fragments, the team estimated a significant percentage of casualties where the severity of the wounding was reduced. The United States Army established a specification for the material which has undergone many minor revisions in 20 years [6].

Many laboratories initiated research studies of fabric armor partly to determine why nylon exhibited good ballistic performance, and to maintain and monitor this good performance. In addition, it was hoped to utilize nylon in such a manner as to improve its performance or to obtain another fibrous material with superior performance. Occasionally, the nylon fell below its projected performance of a ballistic limit of 373 m/s utilizing the 1.1 g, 0.22 caliber ogive point cylindrical missile. Some of the results showed that scouring or rescouring could improve this performance. One reason set forward for this failure was considered to be the slipperiness of the fabric due to residual spinning oils which in turn caused yarn-to-yarn slippage. High humidity, which lowers the modulus and other physical properties of nylon, was also suggested to be responsible for lower ballistic properties [7].

Many studies were conducted to determine the relative ballistic resistance of various fibrous materials along with the mechanical properties of these same fibers. Typical of these studies was one by Weiner and Vadala [8] at Natick Research and Development Command where two saponified acetate fibers (Fortisan and X-36), nylon, and fiberglass were evaluated. The poorest material ballistically was fiberglass fabric. A linear relationship was obtained for the ballistic limit of fiberglass as a function of areal density. However, the whole range was low with limits less than 335 m/s at 7.6 kg/m^2 and 304 m/s at 6 kg/m^2, which is an areal density slightly above the standard for the United States Army nylon vest.

Nylon was woven into different designs of fabric. Although differences in protection could be obtained by different weaves and weights, the ballistic limit at the standard areal density was in a narrow range of 372 to 384 m/s. The Fortisan rayon was a close second to nylon with a ballistic limit of 370 m/s. This Fortisan was highly oriented with a strength of 700 mN/tex (8 g/d), which was quite phenomenal in 1950 [8].

Scientists at the National Bureau of Standards studied the properties of fiberglass, polyester, rayon, nylon, silk, and acetate yarns under longitudinal and transverse impact at rates up to 14 000%/s. Longitudinal impact tests are useful because the results can be correlated with lower rate tensile tests, while transverse impact tests have the advantage of representing the ballistic impact condition where the fragment strikes yarns perpendicular to their long axes. They found that moduli and breaking tenacities rose with

ultimate properties (tenacity at break, elongation to break, and work to rupture) and the stress wave velocity (related to the square root of the modulus divided by the density) should be of major importance in determining the V_{50} of the resultant fabric structure. With the limited data available several plots are possible, namely: V_{50} vs work to rupture of the yarns, kinetic energy of the missile vs work to rupture of the yarns (J vs J/g) or even V_{50} vs some additive function of strength and elongation. One of these graphs (missile energy vs work to rupture of component yarns) is shown in Fig. 3. Regardless of which type of plot is used, the ballistic resistance of polypropylene is always lower than nylon. This means that a polypropylene fabric composed of yarns exhibiting certain stress-strain properties (e.g. tenacity and elongation to break) will exhibit poorer ballistic resistance than a nylon fabric composed of yarns with equivalent stress-strain properties. This problem can be overcome by producing a polypropylene yarn with an extremely high strength in order to meet the ballistic requirements [35]. The highest missile energy value shown for polypropylene in Fig. 3 represents the one case where polypropylene fabric was competitive with nylon. However, this fabric was prepared from an experimental yarn with a strength of nearly 1200 mN/tex (13 g/d). Nylon fabric prepared from yarns with one-third less strength, 800 mN/tex (9 g/d) is just as effective and can be obtained commercially at reasonable cost. It appears that the full potential of polypropylene is not being realized. One possible reason for the relatively low ballistic resistance of polypropylene is the low yarn-to-yarn friction exhibited by polyolefin type fibers. This can be shown in a yarn pull-out test where polypropylene gives a peak pull-out force of only 2/3 of that obtained from a better ballistic material such as nylon or Vinal (polyvinyl alcohol). The pull-out and slip of yarns could also be aided by the relatively greater extension of polypropylene at a definite stress compared to that characteristic of the stiffer nylon, Fortisan, and Vinal yarns. To date, no successful treatment has been developed to bring the ballistic resistance of polypropylene up to the level predicted from the yarn stress-strain properties. Attempts to increase the yarn-to-yarn friction by using colloidal silica or even to decrease the friction with a lubricant or silicone were unsuccessful as judged by little change in ballistic limit values [35].

The first opportunity to investigate glass-like organic fibers came with the development of the aromatic polyamide-hydrazide fibers by Monsanto Chemical Company [36]. They were known as the X-500 series of fibers and they possessed unusually high moduli, high strengths, and generally low elongations to break. The first two properties combined with the expected high temperature resistance

energy must be absorbed by the body. With the minimum thickness this energy can damage the lungs, liver, or heart. Extra thickness of a material cushions the blow, decreasing the abrasion and trauma [46,47]. For this reason, to ensure the complete safety of the officers, a nine-ply undervest or jacket liner is provided. The extra material is also useful to ensure protection against the second threat, the 0.22 caliber projectile. This second threat is difficult to stop because of its sharp point. A sharp point, or long thin projectile, is always more difficult for a fibrous material to defeat. The resulting vest has an areal density of 2.44 kg/m^2 and a total mass of about one kilogram. For the second two threats which involve higher velocities and considerably more kinetic energy, a second nine-ply vest is used raising the mass to two kilograms. This vest and adaptations thereof as liners for jackets have been furnished to 500 000 law enforcement officers. Many shooting incidents have taken place and the vests have proven very effective.

A factor which has been important in all armor, the effect of moisture, becomes even more important with the law enforcement vest. For the 0.22 caliber hand gun threat, losses in the ballistic protective capacity of up to 40% are experienced with Kevlar vests when wet. In comparison, nylon or Kevlar when used by the military against fragment hazards suffer much smaller losses when wet. The reason for this difference is that the 0.22 caliber projectile is sharply pointed and moisture can lubricate the yarns enough to aid the passage of the missile without breaking yarns and absorbing energy. To counter the deleterious effects of moisture, a water repellent treatment is applied to the Kevlar fabric which is composed of a fluorocarbon and an extender (usually a melamine hydrophobe or a quarternary ammonium complex). This type of treatment is used for both the military fragment vests and for the law enforcement type vests [44,48]. The treatment is effective and durable and has reduced the losses due to fabric wetting to insignificant levels.

Hansen and Laible [41] and others have attempted to explain why Kevlar has such phenomenal stopping power with reasons such as high strength, fast stress dissipation (high sound wave velocity), high heat resistance, and fibrillation (longitudinal splitting of the fiber under impact). Certainly no one factor appears to be universally important for all fibers as shown by the fact that high strength polypropylene was not as effective as lower strength nylon.

Wilde et al. [49] studied the energy extracting ability of a series of heavy nylon yarns (1100 tex) using a transverse impact tester. The nylons varied considerably in strength from 88-750 mN/tex (1-8.45 g/d). The energy extracted was measured by determining the velocity of the missile before and after impact of the yarn and this

United States Patent [19]
Hogenboom et al.
[11] Patent Number: 5,035,111
[45] Date of Patent: Jul. 30, 1991

[54] COMBINATIONS OF POLYMER FILAMENTS OR YARNS HAVING A LOW COEFFICIENT OF FRICTION AND FILAMENTS OR YARNS HAVING A HIGH COEFFICIENT OF FRICTION, AND USE THEREOF

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[21] Appl. No.: **251,455**

[22] Filed: **Sep. 30, 1988**

[30] **Foreign Application Priority Data**

Oct. 2, 1987 [DE] Fed. Rep. of Germany 3733427

[51] **Int. Cl.**^{5} **D02G 3/04**; D02G 3/38; D01H 4/00

[52] **U.S. Cl.** **57/224**; 57/231; 57/236; 57/244; 57/256; 428/377

[58] **Field of Search** 57/236, 231, 224, 244, 57/256; 428/377

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Primary Examiner—James C. Cannon
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

The invention relates to combinations of polymer filaments or yarns of high tensile strength, high modulus and low coefficients of friction and filaments or yarns of high coefficients of friction. Combinations of this type, which have been produced in particular by core spinning the filaments or yarns of low coefficient of friction with filaments or yarns of high coefficients of friction or by twisting the two filament or yarn components, are suitable in particular for producing bulletproof wovens, knits and nonwovens.

22 Claims, No Drawings

COMBINATIONS OF POLYMER FILAMENTS OR YARNS HAVING A LOW COEFFICIENT OF FRICTION AND FILAMENTS OR YARNS HAVING A HIGH COEFFICIENT OF FRICTION, AND USE THEREOF

The present invention relates to combinations of polymer filaments or yarns having low coefficients of friction with filaments or yarns having high coefficients of friction.

Filaments having a high tensile strength and a high modulus consist in general of polymers having high molecular weights and are highly drawn. The surface of such filaments is in general very smooth. Accordingly, the coefficients of friction of such filaments are low. Such filaments, or rather yarns, wovens, knits or nonwovens produced therefrom, are used for many purposes where the high tensile strength and the high modulus of these filaments are useful. For instance, such filaments would be useful for producing bulletproof woven or nonwoven materials. However, wovens or nonwovens produced from such filaments have the disadvantage that the smooth surface, and hence the low coefficient of friction, of the filaments forming the woven or nonwoven materials and the associated good gliding action make it relatively easy for an impacting bullet to move these filaments apart, so that despite the high tensile strengths and moduli of such plastics filaments, the bulletproof wovens and nonwovens produced therefrom are still not totally satisfactory.

To eliminate this disadvantage, such polymer filaments having low coefficients of friction and a high tensile strength and high moduli have been roughened mechanically and/or chemically or been provided with coatings to reduce the gliding action mentioned and to stop penetration by bullets due to the individual filaments being moved apart. Roughening reduces the tensile strength of the filaments to a substantial degree, so that the woven materials produced from roughened filaments are still not satisfactory, while the application of coatings is time-consuming and costly.

It is therefore an object of the present invention to make it possible, while retaining the high tensile strength and modulus values of polymer filaments having low coefficients of friction, nonetheless to produce woven, knits and nonwoven materials whose fiber or yarn components cannot be moved apart by impacting bullets on account of their low coefficients of friction (smooth surface) and the associated gliding action.

This object is achieved by the combination according to the invention of polymer filaments or yarns having a high tensile strength, high moduli and low coefficients of friction and filaments or yarns having high coefficients of friction.

According to the invention, polymer filaments having high tensile strengths and moduli and low coefficients of friction are therefore combined with filaments having high coefficients of friction, so that they, while retaining their tensile strength values and moduli, no longer have smooth surfaces and accordingly no low coefficients of friction and therefore are particularly suitable for producing bulletproof woven, knits or nonwoven materials.

It is not only possible to combine filaments having low coefficients of friction with those having high coefficients of friction, but also to modify, in the desired manner, types of yarn composed of filaments having low coefficients of friction by combination with either filaments or types of yarn having high coefficients of friction.

Advantageously, the filaments or types of yarn having low coefficients of friction are combined with the filaments or yarns having high coefficients of friction by core spinning the filaments having low coefficients of friction with filaments having high coefficients of friction or by twisting the two types of filament or yarn.

The filaments or yarns having low coefficients consist in particular of polyolefins, polyvinyl alcohols, polyamides or polyesters, but all filaments having low coefficients of friction and high tensile strengths and moduli, in particular of more than 2 GPa and 60 GPa respectively, may be useful.

In the combinations according to the invention, particularly suitable filaments having low coefficients of friction, and yarns produced therefrom, are those which have been produced by the gel process and subsequently highly drawn, in particular to draw ratios of more than 20, in particular more than 30.

The gel process, which is described for example in more detail in DE Offenlegungsschrift No. 3,724,434, comprises essentially dissolving the particular polymer which, to obtain high tensile strength and modulus values, is of high molecular weight in a solvent, molding the solution at a temperature above the dissolving temperature of the polymer into a filament, cooling the filament, for gelling, down to a temperature below the dissolving temperature, and then drawing the gel filament with solvent removal.

Preferably, the filaments or yarns having low coefficients of friction in the combinations according to the invention consist of polyethylenes, in particular linear polyethylenes, having an ultrahigh molecular weight of more than 600,000 g/mol (weight average of molecular weight). These polyethylenes may contain minor amounts, preferably not more than 5 mol %, of one or more other alkenes copolymerizable therewith, such as propylene, butylene, pentene, hexene, 4-methylpentene, octene etc. Preferably, the polyethylenes can have 1 to 10, in particular 2 to 6, methyl or ethyl groups per 1,000 carbon atoms. However, it is also possible to use other polyolefins, for example propylene homopolymers and copolymers; furthermore, the polyolefins used may also contain minor amounts of one or more other polymers, in particular alkene monopolymers. Filaments of this type can be produced for example by the processes described in GB-A-2,042,414 and -2,051,667.

The filaments or yarns having high coefficients of friction can comprise any desired natural or synthetic filaments or yarns which either as such already have a high coefficient of friction or have been provided with a high coefficient of friction by conventional mechanical and/or chemical roughening or by applying the coating. The roughening can be effected by means of a corona treatment. With these filaments or yarns it is immaterial that their tensile strength suffered due to the roughening treatment. Particularly suitable filaments or yarns having a high coefficient of friction are rubber filaments or yarns and also filaments or yarns made of cotton, elastomers, polyacrylates, polymethacrylates and polyurethanes.

Advantageously it is of course the case that the proportion of filaments or yarns having high coefficients of friction is kept low in relation to the proportion of filaments or yarns having a smooth surface but high tensile strength and modulus values and is in particular be-

tween 5 and 30% by weight based on the proportion of the filaments or yarns having a smooth surface.

If the combinations according to the invention consist of filaments or yarns having low coefficients of friction which have been produced by core spinning with filaments and/or yarns having high coefficients of friction, then the proportion of filaments or yarns having high coefficients of friction is preferably between 5 and 25% by weight, while the amount in the case of twisting ranges between 5 and 30% by weight, in particular between 10 and 20% by weight.

It is also advantageous to combine very thick filaments or yarns having low coefficients of friction and very thin filaments or yarns having high coefficients of friction (rough surface), to ensure very high tensile strength and modulus values for the wovens, knits and nonwovens produced from these filaments.

Experiments have proven that the structures according to the invention have better impact resistance and better energy absorbing properties.

We claim:

1. A filament or yarn having utility in production of bullet-proof articles comprising a first fiber consisting essentially of at least one of a polyolefin and a polyvinyl alcohol, core spun or twisted with a second fiber having a higher coefficient of friction than said first fiber and consisting essentially of at least one of cotton, an elastomer, a polyacrylate, a polymethacrylate, and a polyurethane,

wherein said first fiber has a higher tensile strength and a higher modulus than said second fiber and,

wherein the proportion of said second fiber is a minor amount by weight.

2. A filament or yarn according to claim 1, wherein the fibers have been produced by a gel process and have been highly drawn.

3. A filament or yarn according to claim 1, wherein the proportion of filaments or yarns having a high coefficient of friction is 5 to 30% by weight in relation to the proportion of filaments or yarns having a low coefficient of friction.

4. A filament or yarn according to claim 1, wherein the first fiber consists of polyethylenes having a weight average molecular weight of more than 600,000 g/mol.

5. A filament or yarn according to claim 4, wherein said polyethylene comprises linear polyethylene.

6. A filament or yarn according to claim 1, wherein said second fibers have a roughened surface.

7. A filament or yarn according to claim 6, wherein said roughening is effected by corona treatment.

8. A filament or yarn according to claim 1, wherein the proportion of filaments or yarns having a high coefficient of friction is 5 to 25% by weight in relation to the proportion of filaments or yarns having a low coefficient of friction.

9. A filament or yarn according to claim 1, wherein the proportion of filaments or yarns having a high coefficient of friction is 10 to 20% by weight in relation to the proportion of filaments or yarns having a low coefficient of friction.

10. A filament or yarn comprising a first fiber consisting essentially of at least one polyolefin, core spun or twisted with a second fiber having a higher coefficient of friction than said first fiber and consisting essentially of at least one of cotton, an elastomer, a polyacrylate, a polymethacrylate, and a polyurethane,

wherein said first fiber is an ultrahigh weight average molecular weight gel-processed-highly-drawn fiber having a higher tensile strength and a higher modulus than said second fiber and,

wherein the proportion of filaments or yarns having a high coefficient of friction is 5 to 30% by weight in relation to the proportion of filaments or yarns having a low coefficient of friction.

11. A filament or yarn according to claim 10, wherein the first fiber consists essentially of polyethylenes.

12. A filament or yarn according to claim 10, wherein said second fibers have a roughened surface.

13. A filament or yarn according to claim 10, wherein the first fiber consists essentially of polyethylenes, and said second fibers have a roughened surface.

14. A filament or yarn according to claim 10, wherein the proportion of filaments or yarns having a high coefficient of friction is 5 to 25% by weight in relation to the proportion of filaments or yarns having a low coefficient of friction.

15. A filament or yarn according to claim 14, wherein the first fiber consists essentially of polyethylenes, and said second fibers have a roughened surface.

16. A filament or yarn according to claim 10, wherein the proportion of filaments or yarns having a high coefficient of friction is 10 to 20% by weight in relation to the proportion of filaments or yarns having a low coefficient of friction.

17. A filament or yarn according to claim 16, wherein the first fiber consists essentially of polyethylenes, and said second fibers have a roughened surface.

18. An article produced from a filament or yarn comprising a first fiber consisting essentially at least one of a polyolefin and polyvinyl alcohol core spun or twisted with a second fiber having a higher coefficient of friction than said first fiber,

wherein said first fiber has a higher tensile strength and a higher modulus than said second fiber and,

wherein the proportion of said second fiber is a minor amount by weight and,

wherein the article is substantially bulletproof.

19. An article according to claim 18, wherein the fibers having a high coefficient of friction have a roughened surface.

20. An article according to claim 17, wherein said roughening was effected by chemical or mechanical roughening or a combination thereof.

21. A filament or yarn according to claim 19, wherein said roughening was effected by corona treatment.

22. An article according to claim 18, wherein at least a portion of the filaments or yarns have been subjected to corona treatment.

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US005225241A

United States Patent [19]

Dischler

[11] **Patent Number: 5,225,241**

[45] **Date of Patent: Jul. 6, 1993**

[54] **BULLET RESISTANT FABRIC AND METHOD OF MANUFACTURE**

[75] Inventor: **Louis Dischler**, Spartanburg, S.C.

[73] Assignee: **Milliken Research Corporation**, Spartanburg, S.C.

[21] Appl. No.: **817,191**

[22] Filed: **Jan. 6, 1992**

Related U.S. Application Data

[62] Division of Ser. No. 779,806, Oct. 21, 1991.

[51] Int. Cl.^{5} B05D 5/12

[52] U.S. Cl. 427/121; 427/378; 427/389.9

[58] Field of Search 427/121, 389.9, 378; 428/265, 267, 378, 395, 902, 911; 528/423

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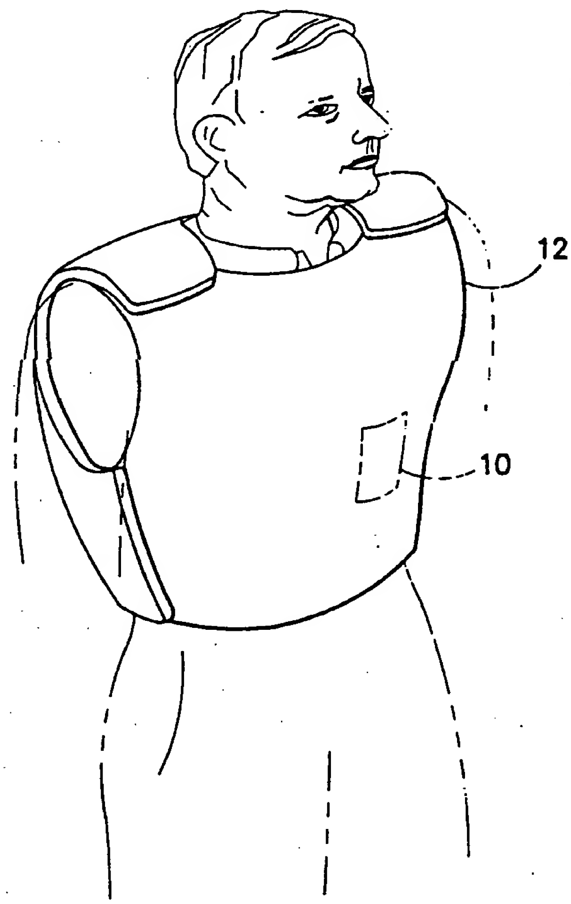
Primary Examiner—Michael Lusigan
Attorney, Agent, or Firm—Earle R. Marden; Terry T. Moyer

[57] **ABSTRACT**

A method for imparting ballistic resistant characteristics to a textile fabric by placing a polymer film on the fibers of a high tenacity fiber fabric which has a coefficient of friction higher than the coefficient of friction of the high tenacity fibers. The fabric, after the placement of the polymer film is subjected to a high velocity air stream to break up any fiber-to-fiber bonds in the fabric.

1 Claim, 1 Drawing Sheet



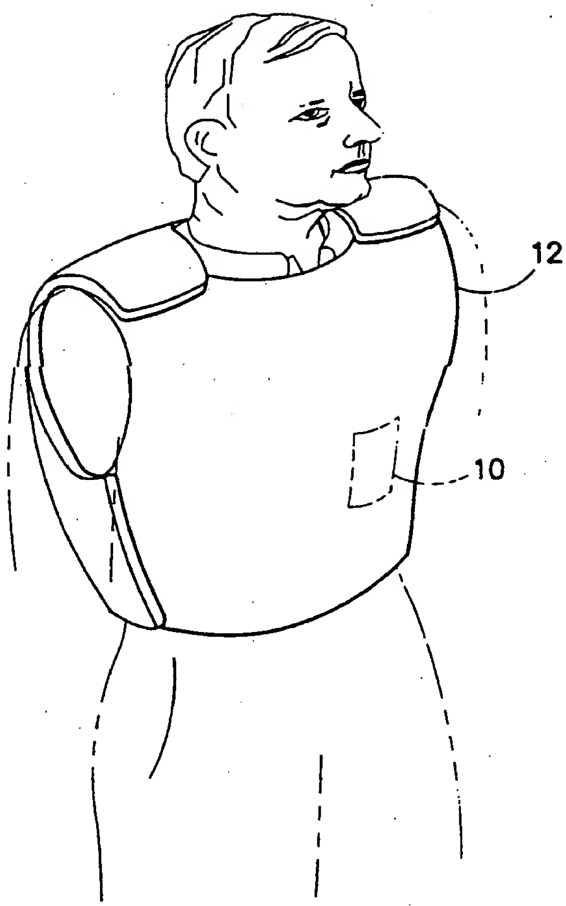


FIG. -1-

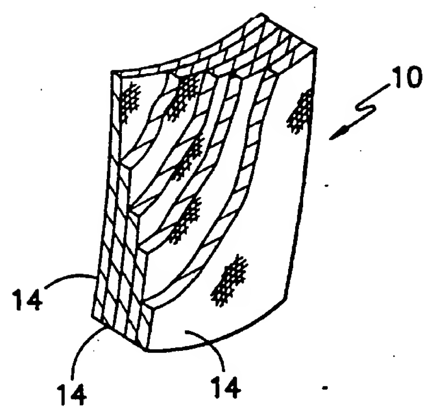


FIG. -2-

BULLET RESISTANT FABRIC AND METHOD OF MANUFACTURE

This is a division of application Ser. No. 779,806 filed Oct. 21, 1991 for bullet resistant fabric and method of manufacture.

The present invention relates to combinations of polymeric fibers having low coefficients of friction with polymeric coatings having high coefficients of friction to provide a fabric which is more resistant to penetration by metallic or other objects such as bullets, flechettes, shrapnel, etc.

Polymer fibers having high tensile strength and high modulus typically are highly oriented, resulting in very smooth fiber surfaces and a low coefficient of friction. Such fibers, when used in the construction of ballistic fabrics, exhibit poor energy transfer to neighboring fibers during ballistic impact, resulting in loss of stopping efficiency. Because of this loss of efficiency, more fabric layers are required to stop a projectile of a given velocity. Known methods of increasing the coefficient by roughing such as sanding or corona treatment have limited utility due to the degradation in tensile strength of the fiber.

Another method of increasing energy transfer between adjacent fibers or yarns in ballistic fabric is to coat the fabric with a polymer having a high coefficient of friction. One deficiency in this approach is fiber to fiber bonds that may form, resulting in stress reflections at yarn crossovers during ballistic impact and premature fiber breakage. Another deficiency is the large weight gain typical of coatings, which may be several percent. This added weight degrades the ballistic efficiency, which is taken as the energy adsorbed per unit areal density. Since the coating itself has negligible tensile strength when compared to the fiber, it reduces the average tensile strength of the fabric. Yet another deficiency of some coatings is a lack of adequate adherence of the coating to the smooth fiber surface. Material that is stripped off during a ballistic impact can serve to reduce the effective coefficient of friction by acting as a dry lubricant between fibers.

Hogenboom, et al., U.S. Pat. No. 5,035,111, disclose a method for improving the ballistic performance of fabric by core spinning high strength fibers in combination with weaker fibers having a higher coefficient of friction. These relatively high friction fibers, present at a 5 to 25% level by weight, degrade the ballistic efficiency in the same manner as high add-on coating. Although gains in ballistic performance may be made by increasing the energy transfer yarn to yarn, concomitant reductions in performance must necessarily result from the presence of large amounts of ballistically inferior fiber.

It is an object of the present invention to supply a ballistic fabric composed of high strength, high modulus polymeric fibers, coated with a thin, high friction polymeric material.

It is a further object of this invention to supply said fabric with a coating tenaciously adhering to the fibers of the substrate with few or no fiber to fiber bonds.

Other objects and advantages of the invention will become readily apparent as the specification proceeds to describe the invention with resect to accompanying drawings, in which: a flexible impact resistant article of clothing is shown with a portion thereof in cross-section to show the construction thereof.

BRIEF DESCRIPTION OF THE DRAWING

In the drawings,

FIG. 1 is a perspective view of a person wearing a bullet proof vest using a fabric made by the method disclosed herein, and

FIG. 2 is a piece of the fabric of the vest of FIG. 1 shown in partial cross-section.

Looking now to the drawing, the fabric **10** is shown made into a bullet resistant vest **12** and basically comprises a multiplicity of Kevlar fabrics **14** treated as herein-described and connected together by stitching or other means to form the vest **12**. The outer face of the vest **12** can be treated with a water repellant finish, if desired.

According to the invention, it has been found that a polymer film deposited on the fiber by the method described in Kuhn, et al., U.S. Pat. Nos. 4,803,096; 4,877,646; 4,981,718; 4,975,317 and 5,030,508 improves the ballistic performance of fabrics measurably. A polypyrrole film, when deposited onto the fiber composing a Kevlar fabric at a film thickness of about 0.15 microns, was found to increase the flechette resistance by about 19%. A flechette is a military weapon that resembles a nail with small fins which when launched at ballistic velocities is unusually penetrating. When tested against a 0.22 caliber bullet fired from a rifle, an 18 layer stack of coated Kevlar fabric was penetrated to a depth of only 3 or 4 layers, as compared to a depth of 6 or 7 layers for an 18 layer stack of uncoated fabric. Furthermore, the coating remained completely adhered to the fiber even in the area of direct impact. Other films, such as polyaniline can be formed so long as the coating has a coefficient of friction higher than the high tenacity fiber of the basic fabric.

In the case of ballistic fabric of exceptionally tight weave, it is found that some debris and crossover bonds do form during the coating, due to a certain amount of dendritic growth. In this case, it is necessary to remove the debris and break apart the bonding which can be accomplished most efficiently by vibrating the fabric by means of air stream directed between the fabric and a rigid plate by one or more air jets as described in U.S. Pat. No. 483,793.

EXAMPLE

Fifty grams of a Kevlar fabric woven in a balanced weave with 200 denier Kevlar 29 warp and weft yarn is placed in a closed container with 29.0 grams of the oxidizing agent $FeCl_3$ with 750 ml of water and agitated at room temperature. Then 2.0 grams of the monomer pyrrole mixed with 250 ml of water was added to $FeCl_3$ solution over a period of 30 minutes while continuing to agitate the container. Then the closed container was agitated for an additional period of 3½ hours to polymerize the pyrrole and coat same onto the Kevlar fabric. The coated fabric was then removed from the container, rinsed and air dried. It was found that the coefficient of friction (8) of the coated Kevlar had increased from 0.19 for the untreated Kevlar fabric to 0.27 for the treated fabric.

Then, since the treated fabric exhibited some crossover bonding and debris the treated fabric agitated by passing a high speed air stream between the fabric and a flat plate as disclosed in U.S. Pat. No. 4,837,902 to cause saw-toothed waves to form in the treated fabric to break apart the bonds formed between fibers to eject the debris collected therein. Air was supplied at 30 p.s.i. as

the treated fabric flowed therethrough at an average fabric speed of about 30 yards per minute. After this treatment the coefficient of friction (f) of the fabric was 0.24 resulting in about a 19% improvement in stopping a flechette than an uncoated fabric.

Although the preferred embodiment of the invention has been described, it is contemplated that changes may be made without departing from the scope or spirit of the invention and it is desired that the invention be limited only by the scope of the claims.

I claim:

1. A method for imparting ballistic resistant characteristics to a textile material, which comprises contacting the textile material with an aqueous solution of an oxidatively polymerizable compound, selected from a pyrrole compound and an aniline compound, and an oxidizing agent capable of oxidizing said compound to a polymer, said contacting being under conditions at which the compound and the oxidizing agent react with each other to form a prepolymer in said aqueous solution before either the compound or the oxidizing agent are adsorbed by, or deposited on or in, the textile material; adsorbing onto the surface of said textile material the prepolymer and allowing the adsorbed prepolymer to polymerize while adsorbed on said textile material so as to uniformly and coherently cover the fibers of the textile material with a film of said polymer and subjecting the treated fabric to a high speed air stream to cause saw-tooth waves to form in said fabric to break apart any bonds formed between fibers of the fabric.

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